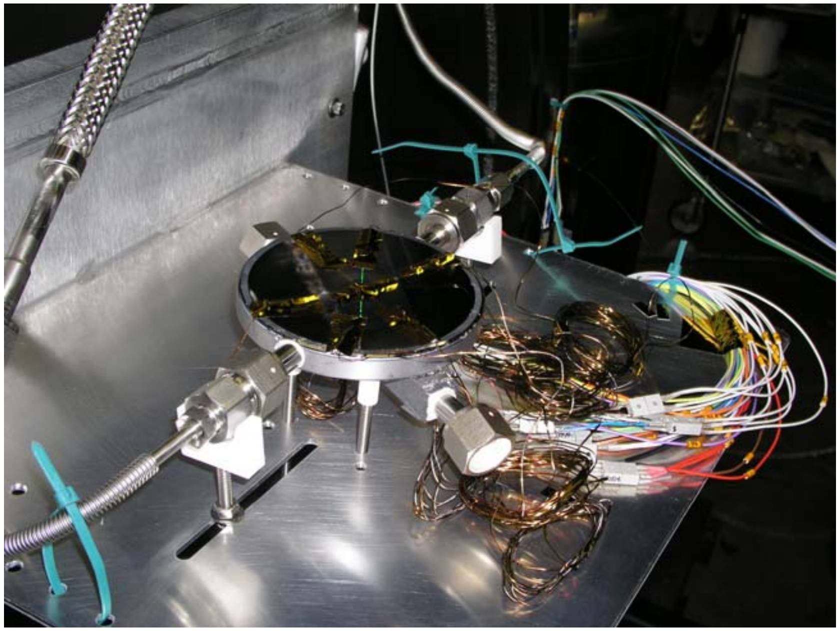
Actively Cooled Silicon Lightweight Mirrors for Far Infrared and Submillimeter Optical Systems
Phase II SBIRContract No, NNM05AA16C
John West and Dr. Phil Stahl NASA MSFC



Dr. Bill Goodman
LWOS Business Lead
Schafer Corporation
2309 Renard Place SE
Albuquerque, NM 87106

505.338.2865

wgoodman@schaferalb.com

Mirror Technology Days
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Outline

- Background
- Why SLMS™ for Cryogenic Optics
- Phase I Results
- Phase II Project

Background

- Achieving a telescope temperature of 4 Kelvin is one of the key technology development demonstrations that must occur in order to unravel the secrets of the early universe
- ~50% of the luminosity of the universe and 98% of the photons (excluding the cosmic microwave background) occur in the FIR
  - ⇒ That is where the young universe is redshifted
- Development of technology for 10-25 meter diameter optics for 20-800 μm bandwidth, with an areal density <5 kg/m^2, and a surface figure specification of $\lambda/14$ at 20 μm required for future FIR/SMM missions
  - ⇒ Premium for wavelengths >100 μm to achieve mirror temperatures lower than 10 K
  - ⇒ Some missions such as TPF-C require extreme figure and finish performance
- TRL 6 must be demonstrated for Cryogenic Optics and Telescopes
- SLMS™ technology development and demonstration effort is directly aligned with the vision of the FIR/SMM community

Why SLMS™ for Cryogenic Optics (1 of 2)

- Super-polishable, low distortion, dimensionally stable silicon skin:
  - ⇒ Avg CTE from 20-310K = 0.95 ± 0.01 ppm/K, 0.25 ppm/K instantaneous @ 20K
  - ⇒ High thermal conductivity: >5000 W/m-K at 25 K
- Silicon foam core is open-celled (up to 95% void space)
  - ⇒ Same CTE as skin, thermal conductivity ~50 W/m-K
  - ⇒ 1st fundamental frequency (120.35 ± 0.175 Hz) and damping (0.0055% ± 0.0043%) are temperature insensitive from 20-300K (20x2x0.5 inch bar measured by JPL – values are geometry dependent)
- *Static and Transient Distortion parameters are incredibly small!*
- SLMS™ engineered construct provides areal density and 1st fundamental frequency that match or exceeds lightweighted beryllium
- *High-stiffness reduces risk for phase matching segments*
- SLMS™ is super-polishable like glass or glass-ceramics
- *Exceptional figure and finish values have been demonstrated*

Why SLMS™ for Cryogenic Optics (2 of 2)

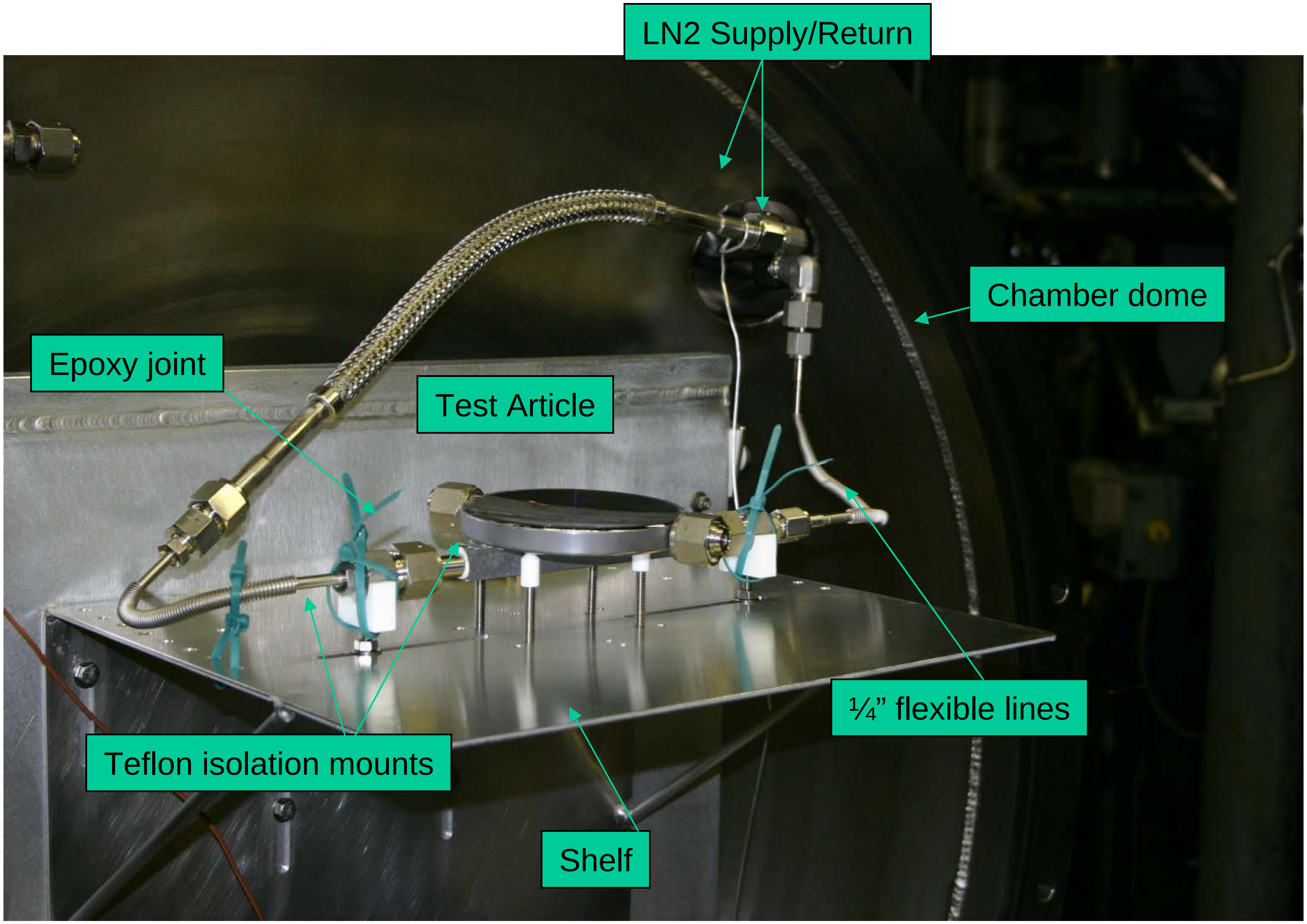
- *SLMS™ can be cooled either Internally or Externally*
- Phase I demonstrated Very Rapid and Uniform cooling for both Internal and External cooling modes with LN2
- Uniform external cooling of skin using Joule-Thompson cooler, or manifold, or cold plate, etc.
- *In situ* heat exchanger for Internal Cooling
  - ⇒ Uniform active cooling by flowing a coolant fluid (e.g. LHe) directly through foam core of mirror
  - ⇒ Foam structure has large surface area, and low flow resistance
  - ⇒ 1 ft^3 of foam has 1500-2000 ft^2 of heat transfer surface area
- Prior testing at NASA MSFC demonstrated minimal print-through (3.7 nm RMS) and figure change ($\lambda/100$ RMS HeNe) for 300 K to 24 K temperature change (radiative)

SLMS™ Transient Distortion Parameter is Orders of Magnitude Better Than Any Other Material

No Cryo-Nulling is Required, No Actuators for Figure Control

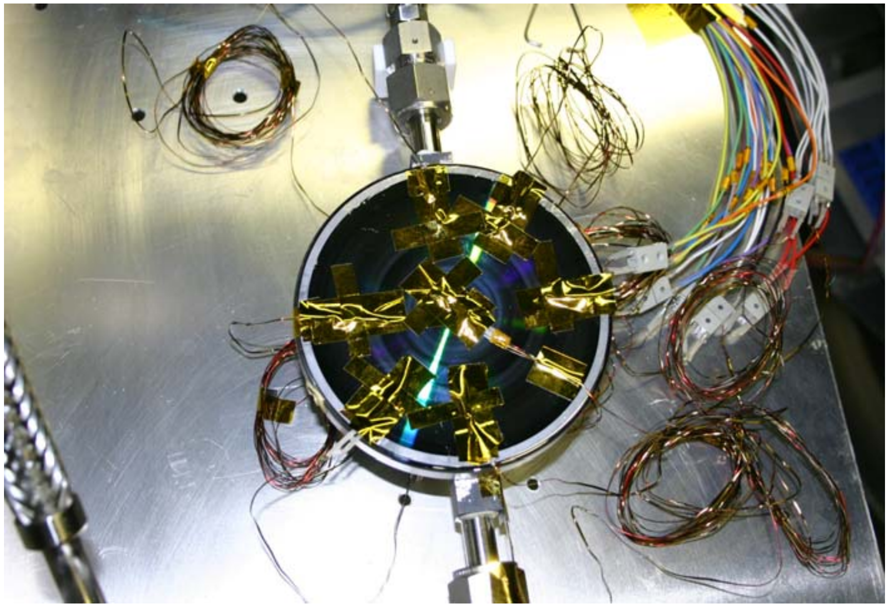
High Stiffness Should Minimize Phase Matching Issues

Test Assembly



4-Foot Vacuum-Ambient Chamber Pumped Down to 10^{-3} Torr for Testing

Setup for External and Internal Cooling



External Flow: Mon 19 July 2004
No Insulation

← N

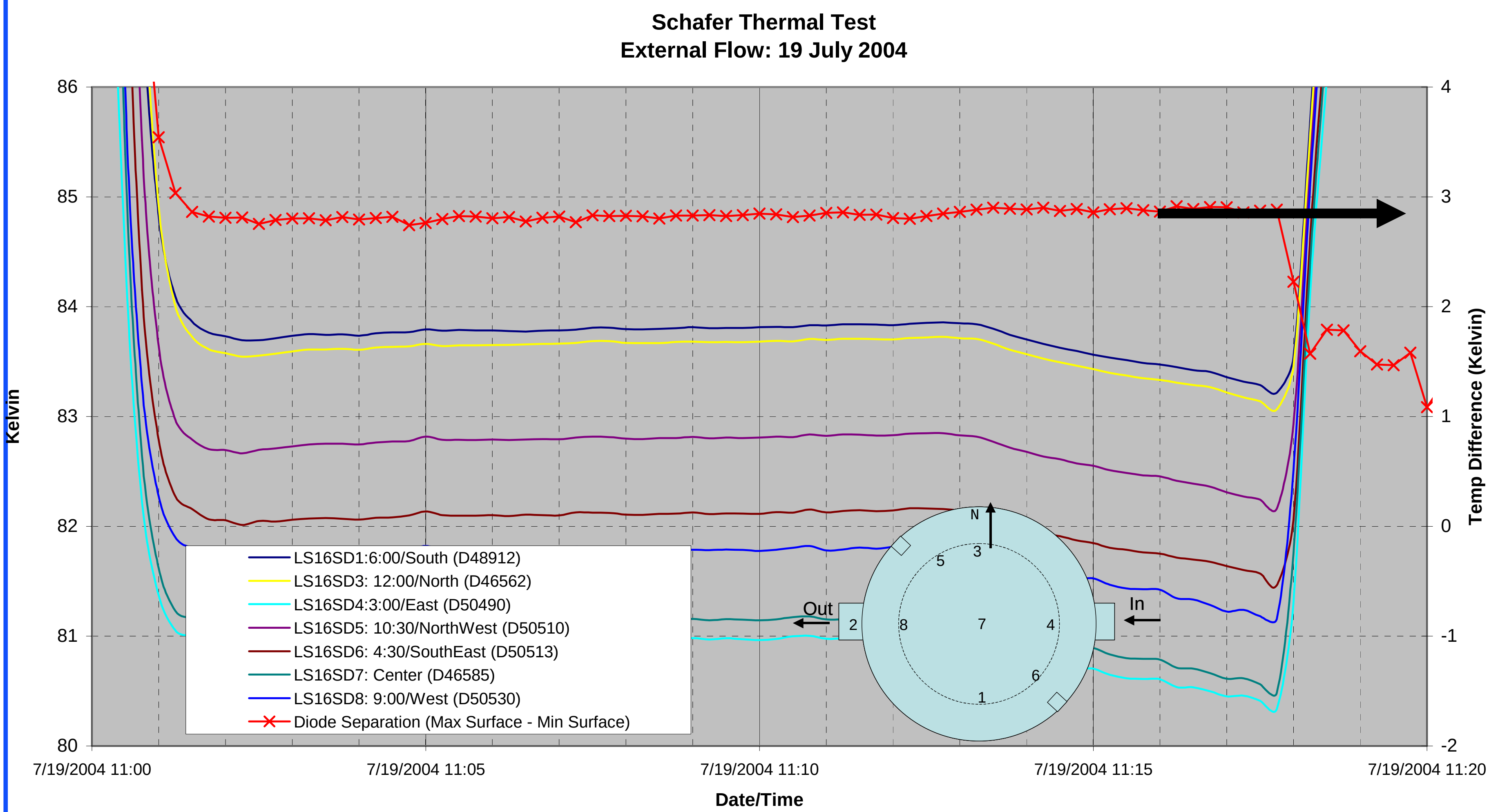
Internal Flow: Tues 20 July & Wed 21 July 2004
No Insulation

↑ N

Flow Highly Non-Optimized – 1 entrance and 1 exit 180 degrees apart

Mirror is a 9.7 kg/m², F/3 Parabola

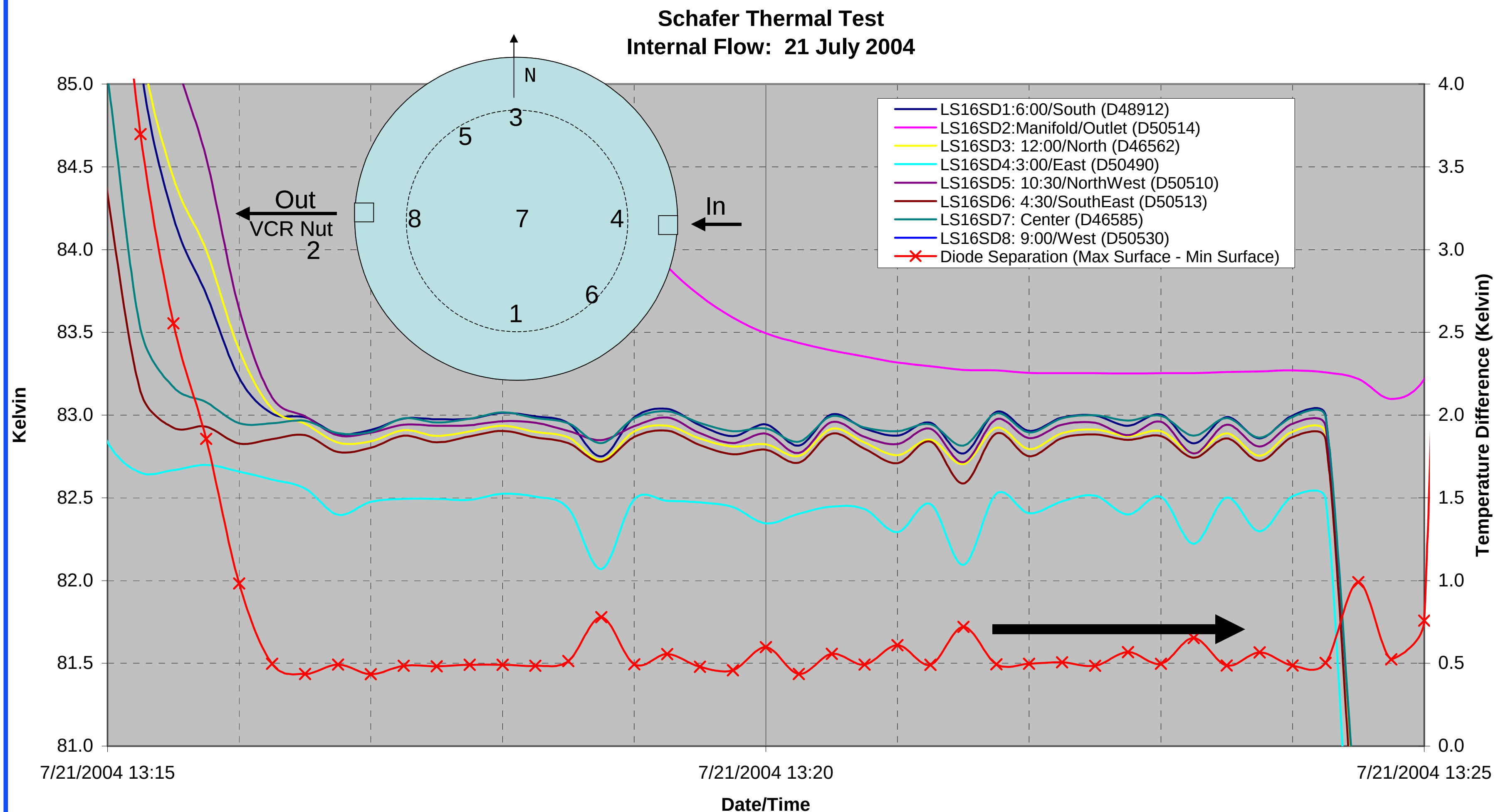
External Flow – No Mirror Insulation



Note: The manifold diode (LS16SD2) detached during cooldown. Not included in difference calculation.

Mirror Reaches Steady State @ 82.4 ± 1.45 Kelvin in <4 minutes

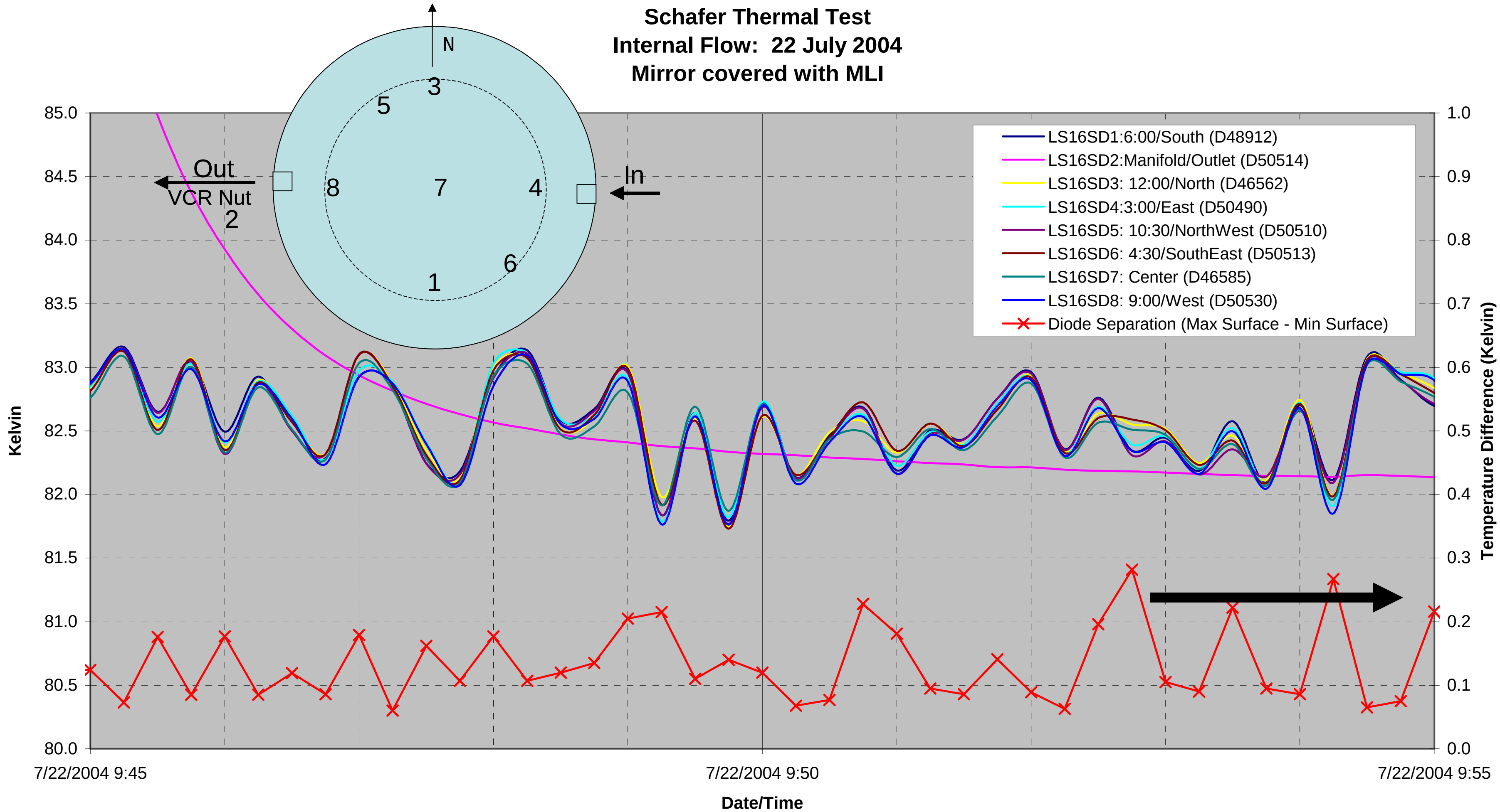
Internal Flow – No Mirror Insulation



Notes: The outlet diode (LS16SD8) detached during cooldown; not included in difference calculation. LS16SD2 was mounted to the SS VCR nut; not included in difference calculation.

Mirror Reaches Steady State @ 82.75 ± 0.25 Kelvin in <4 minutes

Internal Flow – Insulated Mirror



Notes: LS16SD2 was mounted to the SS VCR nut; not included in difference calculation.

Mirror Reaches Steady State @ 82.75 ± 0.075 Kelvin

Phase II Project

- Phase II project tests 55 cm Mirror at 4K using External Active Cooling
- Matures Cryogenic Optic Technology to TRL6
- Far Infrared Submillimeter Prototype (FISP) Mirror
  - ⇒ Optical
    - → CA: 50-cm
    - → ROC: 1500-mm
    - → Kappa: -1.0 (parabola)
  - ⇒ Mechanical
    - → Overall Dia.: 55-cm
    - → Overall thick.: 4.1-cm
    - → Front annulus: 0.7-cm
  - ⇒ Material Properties
    - → 1.3-mm Silicon Closeout
    - → 10-12% Silicon foam
  - ⇒ Mass Properties
    - → Mass = 1.976 kg
    - → Areal density = 9.98 kg/m^2